IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application No.	:	10/590,699	Confirmation No. :	3820
First Named Inventor	:	Ulrich PRECHTEL		
Filed	:	May 23, 2007		
TC/A.U.	:	2832		
Examiner	:	Bernard ROJAS		
Docket No.	:	056226.57920US		
Customer No.	:	23911		
Title	:	High Frequency MEMS Switch Having a Bent Switching Element and Method for Its Production		

CERTIFICATION OF TRANSLATION ACCURACY

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, Christa Schaertel, declare as follows:

1. I am fluent in both the German and English languages;

2. The 22 pages of text in Attachment A, bearing the identification number P 611070/WO/1, titled HIGH-FREQUENCY MEMS SWITCH HAVING A BENT SWITCHING ELEMENT AND METHOD FOR ITS PRODUCTION, constitute an accurate translation of pages 1-16 of Attachment B, bearing the identification numbers WO 2005/083734 and PCT/DE2005/000317; and

3. All statements made herein of my/our own knowledge are true; all statements made herein on information and belief are believed to be true, and further these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and may jeopardize the validity of the application or any patent issuing thereon.

Christa Schaertel 03/20/2009

Christa Schaertel Date

Attachment A

HIGH-FREQUENCY MEMS SWITCH HAVING A BENT SWITCHING ELEMENT AND METHOD FOR ITS PRODUCTION

The present invention relates to a high-frequency MEMS switch having a bent switching element according to the preamble of Claim 1 and to a method of producing a high-frequency MEMS switch having a bent switching element according to the preamble of Claim 11.

MEMS switches or switching elements in the MEMS technology (MEMS = Micro Electro Mechanical Systems) are used in many different fields, such as automobile electronics, telecommunications, medical engineering or measuring technology. As a result of their miniaturization, such switching elements further developed as a micro electro mechanical system are particularly suitable also for space flight applications and satellite systems. High-frequency MEMS switches are particularly also used in radar systems, satellite communications systems, wireless communication systems and instrument systems. High-frequency MEMS switches are, for example, also required in phase antenna facilities and in the case of phase shifters for satellite-based radar systems.

High-frequency MEMS switches offer a number of

advantages, such as an extremely low power consumption, a good insulation or low interference capacities, a low insertion loss or low insertion attenuations and low manufacturing costs.

The article "RF MEMS Switches, Switch Circuits and Phase Shifters" by Gabriel M. Rebeiz et al. in Revue HF No. 2/2001, describes MEMS switches which are used in the high-frequency range, in a range of between 0.1 and 100 GHz. These MEMS switches have cantilever switching arms further developed as mechanical springs which are operated by the effect of electrostatic force for the opening or closing of an electric circuit. The cantilever switching arm or cantilever bar is fastened on a substrate and is electrostatically attracted by an electrode in order to close a contact. Without an applied voltage, the switching arm returns into its starting position as a result of elastic restoring forces, and the contact is opened.

In the case of MEMS switches, the switching operation can be caused in different manners which are basically illustrated as examples in Figures 3a-f. In this case, a switching element influences the traveling of an electromagnetic wave on a signal line by opening or closing a transmission path. This can take place in the manner of a series-parallel switch, of a shunt switch or of a series-shunt switch. In the opened condition of the switching element, a large distance to the contact area is generally necessary because, in this

condition, the capacitance should be as low as possible in order to obtain an interference-free line. However, a short distance is required for the switching operation itself since only low electrostatic forces are active.

The article by C. Chang and P. Chang "Innovative Micromachined Microwave Switch with Very Low Insertion Loss", Proceedings of the 10th International Conference on Solid-State Sensor Actuators (Transducers 99), June 7-10, 1999, Sendai, Japan, Page 1830-33, describes an MEMS switch with a bent switching element which is further developed in the shape of a cantilever bar as a cantilever element. The switching element is fastened above a ground electrode with one end on a substrate, the remaining area of the switching element being oriented upward in a curved manner and projecting away from the substrate. When a switching voltage is applied, the upward-bent switching element is applied to the ground electrode by electrostatic forces, so that the free end of the switching element comes in contact with a signal line. Without the applied switching voltage, the switching element is moved back by an elastic tensile stress into the upward-oriented position in which it is far away from the signal line. During the back-and-forth switching between the two switching conditions, the switching element moves like a frog's tongue.

MEMS switches generally have the problem that the elastic

restoring forces as a rule are very low, so that there is the danger that the switching element clings to the surface of the signal line as a result of adhesion. The switching elements therefore often lack sufficient reliability which is necessary for long-term missions, for example, in space.

It was therefore attempted to provide the switching element with a stronger design in order to thereby achieve stronger restoring forces. However, the electrostatic forces are not sufficient in most cases for reliably causing the switching operations.

It is therefore an object of the present invention to provide a high-frequency MEMS switch having a bent switching element, which ensures a high long-term reliability while the interference capacities are low, in which case a higher mechanical stability and a greater switching force are achieved while the space requirement is low.

This object is achieved by means of the high-frequency MEMS switch having a bent switching element according to Claim 1 and by means of the method of producing a high-frequency MEMS switch having a bent switching element according to Claim 11. Further advantageous characteristics, aspects and details of the invention are contained in the dependent claims, the specification and the drawings.

The high-frequency MEMS switch according to the present invention comprises a signal conductor which is arranged on a substrate; an oblong-shaped switching element which has a bent elastic bending area and is fastened on the substrate in a cantilevered manner; and an electrode arrangement for generating an electrostatic force acting upon the switching element, in order to bend the switching element toward the signal conductor, the switching element in its longitudinal direction being arranged parallel to the signal conductor and having a contact area extending transversely to the switching element partially or completely over the signal conductor, and the elastic bending area of the switching element under the effect of electrostatic force approaching the electrode arrangement parallel to the signal line in a progressive manner.

In the case of the high-frequency MEMS switch according to the invention, the voltage required for closing the element is kept low, a large switching path nevertheless being permitted so that the distance to the open condition is large and the capacitance is therefore low. By arranging the switching element in its longitudinal direction parallel to the signal conductor, a further miniaturization is also achieved, in which case the switching element can nevertheless have a relatively long design, and a higher mechanical stability and a greater switching force can therefore be achieved. In particular, a greater restoring force or a

stronger development of the switching element also become possible. As a result of the large possible length and surface of the switching element, greater electrostatic forces, on the one hand, and greater restoring forces or a thicker development of the switching element, on the other hand, can be achieved.

The switching element preferably comprises at least two switching arms with a bent elastic bending area, which are arranged on both sides of the signal conductor and extend in their longitudinal direction parallel to the signal conductor, the switching arms being connected with one another by a bridge positioned over the signal conductor, which bridge is formed by the respective contact area. The reliability of the MEMS switch is even further increased because still higher restoring forces and electrostatic forces can be achieved while the space and energy demand is low and, as a result, a particularly high mechanical stability and switching force are achieved while the space and energy requirements are low.

The electrode arrangement is advantageously formed by at least one ground or base electrode which is arranged below the switching element in a flat manner on the substrate in order to electrostatically attract the switching element. If the switching arms are arranged on both sides, the base electrode or ground electrode is arranged below each switching arm.

According to another preferred embodiment, the electrode arrangement is formed by a ground electrode arranged below the substrate or by the substrate itself. This results in a simplified production and therefore in reduced production costs. The substrate may be manufactured from high-ohmic silicon.

The electrode arrangement advantageously extends parallel to the substrate surface in order to pull the switching element by the electrostatic force in its bending area progressively to the substrate surface. The bent bending area is preferably formed by bimorphic material.

Another advantageous further development provides that, for generating a tensile stress, the bending area has a surface melted-on, for example, by laser heating. This has the advantage that the tensile stress can be adjusted by the corresponding selection of the duration and intensity of the laser irradiation corresponding to the respective demands. The tensile stress can also be achieved by the appropriate control of the layer deposition during the production.

The switching element is advantageously produced by means of the thin-film technology. As a result, a cost-effective production and a small construction are achieved.

The contact area of the switching element preferably

comes in direct contact with the signal conductor under the effect of the electrostatic force. As an alternative, under the effect of the electrostatic force, the contact area takes up a minimal distance from the signal conductor; that is, it does not come in direct contact with the signal conductor. This results in a high capacitance between the signal conductor and the switching element, so that the signal line is interrupted. The minimal distance can be achieved or maintained, for example, by a suitable dielectric insulation.

The following steps are carried out in the case of the method of producing a high-frequency MEMS switch having a belt switching element according to the invention: Constructing a signal line on a substrate; as required, forming an electrode arrangement on the substrate, for example, if the substrate has no intrinsic conduction; forming an oblong switching element having a bent elastic bending area on the substrate such that, in its bending area, it is pulled by the electrode arrangement by an electrostatic force lengthwise toward the substrate and, by an elastic restoring force, in the bending area, moves away from the substrate; the switching element in its longitudinal direction parallel to the signal conductor being arranged such that a laterally projecting contact area of a the switching element extends transversely over the signal conductor, so that the elastic bending area of the switching element under the effect of the electrostatic force parallel to the signal line progressively approaches the

electrode arrangement in order to bring the contact area in the proximity of the signal conductor. The electrode arrangement may also be formed by an intrinsically conducting substrate or an intrinsically conducting substrate area.

By means of the method, a particularly reliable high-frequency MEMS switch having a bent switching element is produced in a cost-effective manner, which has an increased mechanical stability and higher switching forces.

Advantageously, the switching element is shaped such that it has at least two switching arms having a bent elastic bending area, the switching arms being arranged on both sides of the signal conductor, so that they extend in their longitudinal direction parallel to the signal conductor, and the switching arms are connected with one another by a bridge positioned over the signal conductor, which bridge is formed by the respective contact area.

Preferably, at least one base electrode as the electrode arrangement under the switching element is arranged flatly on the substrate. At least one ground electrode arranged below the substrate can also be formed as the electrode arrangement. Advantageously, the bending area is formed by bimorphic material. However, it is particularly advantageous for the surface of the bending area to be melted on by means of laser heating for generating a tensile stress. In particular, the

method can be used for producing the high-frequency MEMS switch further developed according to the invention, as it is generally described above.

In the following, the invention will be described by means of the figures.

Figure 1 is a schematic perspective view of a high-frequency MEMS switch according to a particularly preferred embodiment of the invention;

Figure 2 is a schematic top view of an arrangement of MEMS switches according to further preferred embodiments; and

Figures 3a - f are schematic views of different switch configurations of MEMS switches.

Figure 1 illustrates a particularly preferred embodiment of a MEMS switch 10 which is suitable for high-frequency applications and has two parallel switching arms. The MEMS switch 10 comprises a substrate 11 on which a signal line 12 is constructed which extends in one direction over the substrate 11. An upward-bent switching element 13 is fastened on the substrate, which switching element 13 in this example comprises two longitudinally developed switching arms 13a, 13b extending parallel to one another. The switching arms 13a, 13b of the switching element 13 are each fastened with one end

flatly on the substrate surface and parallel thereto, while their remaining part is bent upward, so that the respective other end of the switching arms 13a, 13b is away from the substrate surface. For this purpose, each switching arm 13a, 13b of the switching element 13 has a central elastic area 131, 132 which is bent or curved upward in the switch position illustrated here.

On the substrate surface, an electrode arrangement is provided below each switching arm 13a, 13b of the switching element 13, which electrode arrangement is formed in this area by two ground electrodes 14a, 14b. The ground electrodes 14a, 14b have the purpose of exercising an electrostatic attraction force on the switching arms 13a, 13b fastened in a cantilevered manner when a switching voltage is present, so that they move toward the substrate surface, in which case the elastic bending areas 131, 132 assume a straight shape.

Furthermore, the switching element 13 comprises a contact area 15 which, in this example, extends transversely over the signal line 12. When an electrostatic force is exercised on the bending areas 131, 132 and the free ends of the switching arms 13a, 13b by means of the electrode arrangement 14a, 14b, the contact area 15 approaches the signal line 12 in order to cause a direct electric contact or a capacitive coupling to the signal line 15. In this case, the MEMS switch 10 is in its closed condition.

In its bending areas 131, 132, the switching element 13 is provided with a tensile stress which causes a restoring force so that the switching arms 13a,13b return into the bent condition when no electrostatic attraction force is exercised upon the switching arms 13a, 13b by the ground electrodes 14a, 14b. In this case, the MEMS switch 10 takes up its open condition, in which the contact area 15 is away from the signal line 12 , and therefore no electric contact exists and no or only a very low capacitive coupling exists to the signal line 12.

With its cantilever switching arms 13a, 13b further developed as oblong bars, the switching element 13 is arranged in its longitudinal direction parallel to the signal line 12. In this case, the contact area 15 forms a bridge which mutually connects the two switching arms 13a, 13b in the area of their free ends and, in this embodiment, extends completely over the signal line 12 transversely to the latter. When electrostatic force acts upon the switching arms 13a, 13b by means of the ground electrodes 14a, 14b, the switching arms 13a, 13b, in steps or continuously, from their fastened ends, approach the ground electrodes in a direction extending parallel to the signal line 12.

Figure 2 is a top view of an arrangement of MEMS switches 20, in which the individual switching elements 23 each only

have one oblong cantilever switching arm 23a, which extends parallel to the signal line 22. Each of the switching elements 23 has one or more contact areas 25 laterally arranged on the respective switching arm 23a, which contact area 25 extends transversely over the signal line 22. In this case, the respective contact area 25 may extend either completely transversely over the entire width of the signal line 22 or only partially. Several contact areas 25 may also be arranged laterally on a switching element 23, as illustrated on the right-hand side in Figure 2.

The switching elements 25, which in Figure 2 are arranged in the center area on both sides of the signal line 22, are aligned such that their opposite contact areas 25 engage in one another in a tooth-type manner above the signal line 22.

The high-frequency MEMS switch 10 illustrated in Figure 1 is constructed in a shunt configuration. In the upward-oriented position of the switching arms 13a, 13b arranged as cantilever elements or in a cantilevered manner, the coupling capacitance is very low because of the distance between the signal line 12 and the contact area 15. The influence on the traveling of an electromagnetic wave on the signal line 12 is therefore also low. When an excitation voltage or switching voltage is applied to the structure, the curved switching element 13 is caused to bend downward, so that the bridge-type contact area 25 reaches the signal line 12 or its direct

proximity, so that a high capacitance is created between the signal line 12 and the switching element 13, whereby the traveling of the electromagnetic wave on the transmission or signal line 12 is prevented or interrupted.

The illustrated switching elements 13, 23 with their switching arms 13a, 13b, 23a and contact areas 15, 25 are produced by thin-film technology, the bent switching elements with their switching arms being arranged parallel to the signal line 12, 25 and, in the embodiment illustrated in Figure 1, being connected by a bridge which is formed by contact area 15. The signal line 12, 22, which extends below the bridge or the contact area 15, 25 on the substrate 11, 21, typically has an electric resistance of, for example, approximately 50 Ω. However, it may also be further developed with other resistances, depending on the requirements of the respective application. The MEMS switch forms a HF relay.

Figures 3a-f show various switch configurations as examples, which can be implemented by means of the MEMS switch according to the invention. Figures 3a and 3b show a switching in series with the signal line 12, the signal line being interrupted in Figure 3a, and the signal line 12 being closed in Figure 3b.

Figures 3c and d show shunt-switch configurations in which the switching takes place by an electric shunt. In this

case, the signal line 12 is closed in Figure 3c because the switch is open and therefore no shunt is present. In Figure 3d, the signal line 12 is interrupted because the switch is closed and the shunt is present.

Figures 3e and f show a combination of a series and shunt configuration, the switch in the signal line 12 being open in Figure 3e, and the shunt being closed in Figure 3f.

The substrate 11, 21 is made of a semiconductor material, while the signal line 12, 22 and the switching element 13, 23 are produced from a highly conductive material, such as Al, Cu, Au, etc.

When producing the MEMS switch, first electrically conductive layers are constructed as the signal line and the electrode arrangement on the substrate. Subsequently, the switching element 13, 23 is fastened in a cantilevered manner on the substrate surface. For generating the bending and the restoring force in the bending area of the switching element, its surface is melted on by means of laser heating in order to create the required tensile stress in the elastic bending area. However, bimorphic material may also be used for causing the curvature and the restoring force into the bent condition. Instead of a ground electrode, a high-ohmic substrate can also be used for generating an electrostatic attraction force. On its backside, this high-ohmic substrate

is provided with a metallization 17 which is used as the ground. This possibility is also schematically illustrated in Figure 1.

During the production, the so-called sacrificial layer used in known processes can be replaced by a suitable surface modification, for example, by water-proofing. As a result, the distance between the switching element and the ground electrode or the substrate surface becomes even shorter, so that considerably larger electric fields and correspondingly lower operating voltages are achieved.

As a result of the bent shape of the switching element in its longitudinal direction parallel to the direction of the signal line, a particularly long switching path becomes possible, so that the distance in the open condition in the case of a small size of the switching element, can nevertheless be designed to be large, and the capacitance in the open condition is therefore low. By means of the arrangement according to the invention, a higher mechanical stability is reached. Furthermore, the switching elements can be provided with a greater restoring force because, as a result of the geometrical arrangement of the electrodes and of the switching elements, a greater electrostatic attraction force can be achieved, in which case, in the opened condition, a low interference capacity is nevertheless present. Particularly in largely autonomous systems and mainly in the

case of satellite applications, an improved long-term stability and a greater reliability are achieved by means of the further development of the high-frequency MEMS switch according to the invention. In this case, the risk of adhesion or generally a clinging or catching of the switching element on the substrate surface or the surface of the signal line is reduced or eliminated.

CLAIMS:

1. MEMS switch having a bent switching element, comprising

a signal conductor (12), which is arranged on a substrate,

an oblong-shaped switching element (13), which has a bent elastic bending area (131, 132) and is fastened in a cantilevered manner on the substrate (11), and

an electrode arrangement (14a, 14b) for generating an electrostatic force acting upon the switching element (13) in order to bend the switching element (13) toward the signal conductor (12),

characterized in that the switching element (13) has at least two switching arms (13a, 13b) having a bent elastic bending area (131, 132), which are arranged on both sides of the signal conductor (12) parallel thereto and are mutually connected at a free end by a bridge (15) positioned over the signal conductor (12),

the switching arms (13a, 13b) being further developed such that the respective elastic bending area (131, 132) under the effect of the electrostatic force progressively approaches the electrode arrangement (14a, 14b) in a direction parallel to the signal conductor (12).

2. High-frequency MEMS switch according to Claim 1, characterized in that the bridge (15) forms a contact area.

3. High-frequency MEMS switch according to Claim 1 or 2, characterized in that the electrode arrangement (14a, 14b) is formed by at least one ground electrode which is arranged under the switching element flatly on the substrate (11) in order to electrostatically attracting the switching element.

4. High-frequency MEMS switch according to Claim 1 or 2, characterized in that the electrode arrangement is formed by a ground electrode arranged below the substrate (11) or by the substrate itself.

5. High-frequency MEMS switch according to one of the preceding claims,
characterized in that the electrode arrangement (14a, 14b) extends parallel to the substrate surface in order to pull the switching element (13) by the electrostatic force in its bending area (131, 132) progressively toward the substrate surface.

6. High-frequency MEMS switch according to one of the preceding claims,
characterized in that the bent bending area (131, 132) is formed by bimorphic material.

7. High-frequency MEMS switch according to one of the preceding claims,
characterized in that the bending area (131, 132) has a surface melted-on by laser heating for generating a tensile stress.

8. High-frequency MEMS switch according to one of the preceding claims,
characterized in that the switching element (13) is produced by thin-film technology.

9. High-frequency MEMS switch according to one of the preceding claims,
characterized that, under the effect of the electrostatic force, the contact area (16) comes in direct contact with the signal conductor (12).

10. High-frequency MEMS switch according to one of Claims 1 to 8,
characterized in that, under the effect of the electrostatic force, the contact area (15) takes up a minimal distance from the signal conductor (12).

11. Method of producing a high-frequency MEMS switch having a bent switching element by

constructing a signal conductor (12) on a substrate (11),

constructing an electrode arrangement (14a, 14b) on the

substrate (11),

forming an oblong switching element (13) having a bent elastic bending area (131, 132) on the substrate (11) such that, in the bending area (131, 132), it is pulled by the electrode arrangement (14a, 14b) by an electrostatic force lengthwise toward the substrate (11) and, by an elastic restoring force, in the bending area (131, 132), moves away from the substrate (11),
characterized in that the switching element (13) comprises at least two switching arms (13a, 13b) having a bent elastic bending area (131, 132) which are arranged on both sides of the signal conductor (12) parallel thereto and are mutually connected at a free end by a bridge (15) positioned over the signal conductor (12),

the switching arms (13a, 13b) being further developed such that, under the effect of the electrostatic force, the respective elastic bending area (131, 132) progressively approaches the electrode arrangement (14a, 14b) in a direction parallel to the signal conductor (12).

12. Method according to Claim 11,
characterized in that the bridge (15) is constructed as a contact area.

13. Method according to one of Claims 11 to 12,
characterized in that at least one ground electrode arranged below the substrate (1) is formed as the electrode

arrangement.

14. Method according to one of Claims 11 to 13, characterized in that the surface of the bending area (131, 132) is melted on by means of laser heating for generating a tensile stress.

15. Method according to one of Claims 11 to 14, characterized in that it is used for producing a high-frequency MEMS switch according to one of Claims 1 to 10.

16. Method according to one of Claims 11 to 15, characterized in that the electrode arrangement (14a, 14b) is formed by one or more intrinsically conducting substrate areas or by one intrinsically conducting substrate.

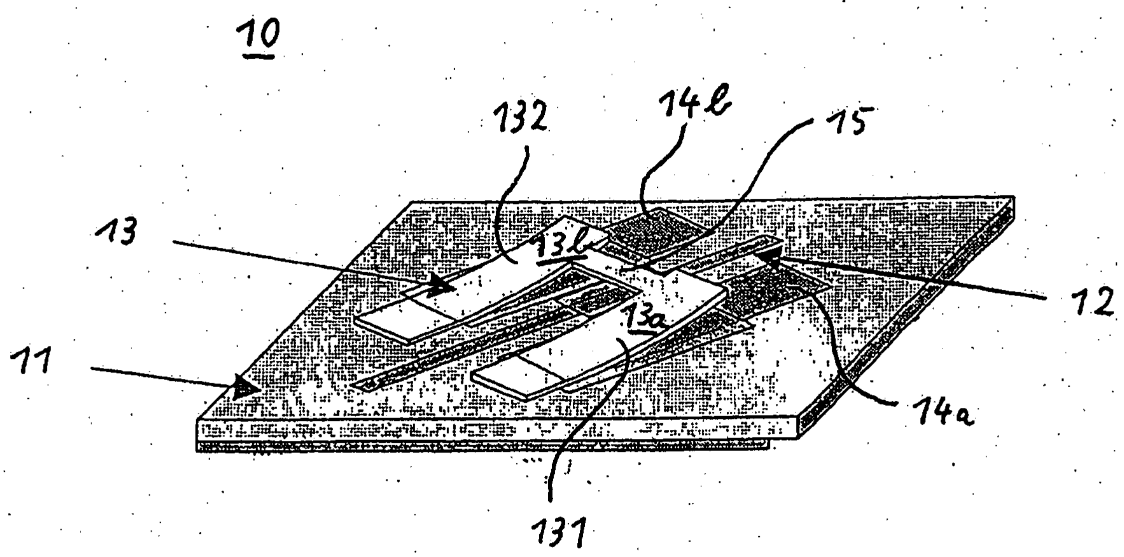
10
132
14b
15
13
13b
12
13a
11
14a
131

Fig. 1

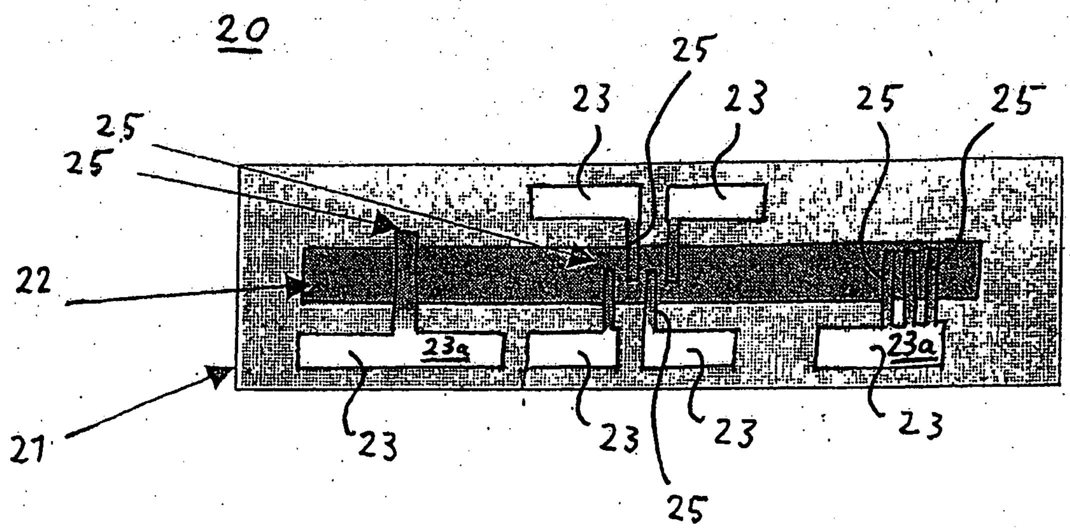
20
25
23
23
25
25
25
25
22
23a
23a
21
23
23
23
23
25

Fig. 2

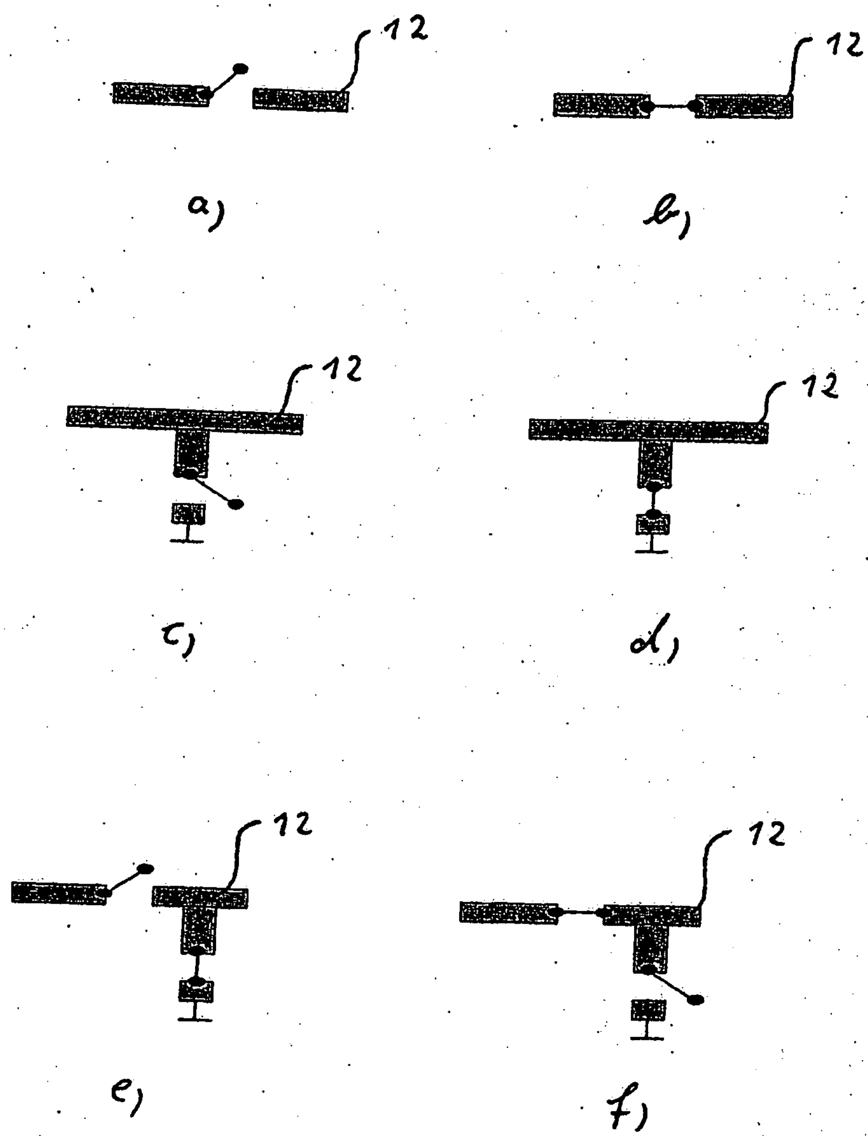

Fig. 3